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EXCERPTS FROM "GIGIYENA TRUDA I PROFESSIONAL'NYYE ZABOLEVANIYA"

[The following are translations of three articles appearing in "Gigiyena Truda i Professional'nyye Zabolevaniya" (Labor Hygiene and Occupational Diseases), Vol III, No 6, Moscow, 1959, pages 3-8, 16-21, and 22-28.]

Establishment of Standard Values of General Vibration

Ye. Ts. Andreyeva-Galanina

The establishment of norms for general vibration is considerably more complicated than in the case of so-called local vibration. Under industrial conditions, vibration may be of different types and may exert different effects. An important place is occupied by pulsating waves which, in a number of cases, present impulses of unequal extinction times (different types of transport).

Industrial vibration is chiefly of a complex nature: it includes vibration of different periods and amplitudes. The direction of vibration may be vertical, horizontal (in two mutually perpendicular planes), or angular. It includes also vibrations which differ depending on the position of the body during work -- either sitting or standing. Of importance also is the time of contact with vibrations and impulses. Hence, in normalizing, it is necessary to take into account a number of factors which, of course, makes the task more difficult.

Normalization is not a new problem but is at least fifty years old. The majority of works of the earlier period undertook the task of determining the limits of subjective sensation, which might serve as a guide in the establishment of permissible limits of vibration. Some

authors, as the basis of physical characteristics, have adopted rate, others acceleration, and a third group have used displacement as the basis.

Digby and Sankey indicate the following gradations of rate of vibration with respect to subjective feeling:

0.005 cm/sec	at the limit of sensation
0.01 "	unpleasant
0.05 "	onset of oppresive sensation
0.1 "	limit of tolerability

Mallok suggests the use of acceleration:

4.9 cm/sec^2	threshold of sensation
9.8 "	uncertain sensation
49.05 "	unpleasant
98.1 "	limit of endurance (threshold of harmfulness)

Geyser, who had at his disposal a large number of observations on the subjective sensation of vibrations of infrasound frequency, presents the following data:

Sensation	Frequency in c/s	Amplitude in cm
Insensible	2-6.5	0.002
Undesirable for homes	5.0	0.007
Unpleasant	10.0	0.0025

If one uses the latter to compute acceleration, we obtain the following:

Insensible	0.32-3.4 cm/sec^2
Undesirable	10.0 "
Unpleasant	7.0 "

Hence, there is a significant difference between the values suggested by Mallok and Geyser. Whereas the former assumes a threshold of unplesantness of 49.05 cm/sec^2, the latter designates this as seven cm/sec^2.

Reyer and Meyster have experimentally established different sensitivities of man to vibrations depending on their character, parameters, and position of the body. Like other investigators, they believe that with small frequencies, acceleration is a factor, whereas with large frequencies, amplitude and rate are factors.

Starting with the degree of sensibility of horizontal and vertical vibrations, they proposed five categories: (1) scarcely sensible vibration, (2) easily sensible vibration, (3) strongly sensible vibration, (4) vibrations capable of inducing injury, (5) vibrations capable of inflicting trauma.

Each of the categories encompasses a range of frequencies from one to 50 c/s. Within the limits of these frequencies, one and the same subjective sensation emerges at different amplitudes.

Table 1 includes average values for amplitudes causing different subjective sensations in a person subjected to vertical and horizontal vibraion in standing and lying positions (Reyer and Meyster). The range of frequencies of 30-50 c/s is sensed as vibration, whereas 20-30 c/s and less is sensed as separate impulses. One and the same subjective sensation arises with an amplitude of vertical displacement approximately half as great as the horizontal, i.e., vertical vibration may exert more influence than horizontal.

The data of Reyer and Meyster may serve as source material for normalization of general vibration and the establishment of separate norms for vertical and horizontal vibration, given different positions of the body.

According to their data, greater amplitudes can be tolerated at low vibration frequency than at high. If we believe that injury may be caused by vertical vibration which is easily sensible to a man standing, then we can derive the following values for amplitude (average) of the indicated range of frequencies:

Less than 10 c/s	60.0 microns
10-20 "	24.0 "
30-50 "	6.5 "

Table 1

The dependence of subjective sensation on parameters of vibration and on the position of the body on a vibrating base.
Amplitude in microns (averages)

Sensation	Vertical					
	Standing			Lying		
	50-30	20-10	Less than 10	50-30	20-10	Less than 10
Scarcely sensible	3,0	7,0	24,0	7,5	15,0	50,0
Easily sensible	6,5	24,0	60,0	12,0	60,0	425,0
Strongly sensible	13,5	65,0	280,0	30,0	270,0	550,0
Injurious	24,0	130,0	550,0	120,0	550,0	More than 550,0
	Horizontal					
Scarcely sensible	5,0	12,0	42,0	4,5	8,0	250,0
Easily sensible	13,0	45,0	102,0	7,0	18,0	510,0
Strongly sensible	40,0	120,0	2575,0[1]	13,0	65,0	575,0
Injurious	50,0	190,0	10,0	48,0	250,0	700,0

1. 10 mm.

Eason considers seven c/s to be a frequency of vibration for which the upper permissible limit of amplitude is 38-50 microns; Geyger, for a frequency range of two to 6.5 c/s, accepts 70 microns as an undesirable amplitude. Hence, the undesirable amplitudes of vibration of low frequencies are very near each other.

The interesting material of Reyer and Meyster has not been put into practice, and has not been used as the basis for the creation of permissible limits of vibration, although this could be done. Apparently, they were used by A. M. Volkov in establishing permissible values of vibration without differentiation of vertical and horizontal displacement.

We shall not list the many other efforts at normalization, all of which have been based on indices of subjective sensation.

Of considerable interest are the studies of Dickman (1956) relative to the influence of mechanical vibration with frequencies from one to 100 c/s on man, and the permissible limits of vibration derived from them. He made a study of physiologic reactions, primarily vegetative, as the most indicative, of the character of subjective sensation, and of the work capacity of the subjects. Taking into account that, under industrial conditions, both vertical and horizontal forms of vibration are found, and that transportation involves angular displacements, he conducted his experiments on special platforms which generated all three of these forms of vibration. The vibrations were strictly sinusoidal and had a spectrum of frequencies from one to 100 c/s, which were of special interest because of their being the most frequently encountered in industry and transport.

The author drew important conclusions - with each frequency determined, different parts of the body are displaced with the same frequency but with different amplitudes, which is due to the different mass and density of separate parts of the body and the flexibility of the connections between them.

In the area of lower frequencies - about four to five c/s - the displacement of the head and especially of

the shoulders is much greater than the amplitude of vibration of the platform. The shoulder girdle moves with an amplitude 75 percent, and the head with an amplitude of 20 percent, greater than the amplitude of the vibrating base.

The marked difference, we believe, is explained by the fact that the standing subject inevitably bends the legs in trying reflexly to compensate for shocks to the internal organs, which leads to a displacement of the body of greater amplitude. A different picture is seen in the case of the head. The special construction of the joints, and the massive muscular connections supporting the head, limit vertical movement much more than could be done by the complex of tissues and joints of the legs, which are primarily supportive in function. These findings of Dickman are in accord with the findings of Müller, who ascertained a critical frequency of four to five c/s.

A frequency of vibration higher than five c/s elicits less vibration of the body, and 20 c/s and more causes either the same displacement as that of the platform, or is not accompanied by any increase whatsoever in vibrational amplitude. This is how the critical value of four to five c/s was determined.

In determining the maximum permissible parameters of vertical vibration, this difference in the reaction of the body and of its separate parts must be taken into account.

The matter is otherwise with displacement of the head during horizontal vibration. First, the displacement takes an elliptical form and is greatest in a sitting subject. In this, the ellipse described by the head is greatest at a frequency of two to three c/s. Obviously, this is the result of a reflex arising from the vestibular apparatus.

Physiologic studies carried out by Dickman permit us to believe that general vibrations with frequencies of five to 40 c/s are most poorly tolerated. In this, with frequencies of less than five c/s, a characterization of acceleration ("b" $\cong af^2$) is most expedient, whereas rate (velocity) is best considered at the higher frequencies ($v \cong af$) (Dickman, 1956).

An assessment of vibration, according to the proposal

of this author, may be carried out by determining the value of K as a derivative of frequency and amplitude. K may be computed according to the following formulae:

Up to five c/s	$K = af^2$	here a is in millimeters
from 5-40 "	$K = 5af$	
from 40-100 "	$K = 200a$	
from 40-100	$K = 0.2a$	here a is in microns

Use may be made of a nomogram, from which it is easy to find the value of K. The character of subjective sensation, the state of work capacity, and the experimental time of tolerance of the vibration also correspond to definite values of K. (Table 2)

Table 2

K	Tolerance of Vibrations	K	Tolerance of Vibrations
0.1	Threshold of sensation	3-10	Unpleasant, interferes with work, can be endured no more than an hour
0.1-03	Scarcely sensible, easily tolerated		
0.3-1	Easily sensible, slightly unpleasant over long periods of time, but tolerable	10-30	Very unpleasant, work almost impossible, can be endured no more than ten min.
1-3	Strongly sensible, unpleasant if long continued, but still bearable	30-100	Extremely unpleasant, tolerable for no more than one minute, work impossible
		more than 100	Intolerable vibration

If one attempts to compute values of K for vibrations occurring in industrial situations or transport, one finds that in the latter its value is greater, lying in the zone of the unpleasant, interfering with work, and

difficult to tolerate (see Table 3).

We have not included in Table 3 values of K for horizontal vibration. In textile plants and in railroad transport, it is much greater, reaching values of K = 48 (textiles) and K = 52-70 (locomotive and passenger cars).

The value of K of horizontal displacement in any form of transport is not only functionally dependent on the construction of the means of transport, but also on the state, construction, and configuration of the routes, as well as on the rate of movement of the transport objects. Hence to devise norms for horizontal vibration is possible only when account is taken of all of these factors. Vaas (1935) indicates that at a rate of 50 km/hr the amplitude is less than at speeds greater or less than this. For persons sitting or lying down, the construction of the seats, the damping properties of the springs, etc. are of importance; this is almost not taken account of in studies by hygienists, and the determination of the necessary value of their aperiodicity is ignored by almost everyone.

Table 3

Designation of object	K	Designation of object	K
Textile shops - vertical vibration	3-6	Trolley	6-8
Wood-working shops - sawdust shops	1.7	Locomotives	3.8-16.5
Processing shops	0.57-0.72	Passenger cars- vertical vibration	1.6-12.5
Mechanics' shops	0.1-1.5	Sailing vessels	4.5-18
Pig-iron rolling mill	up to 1.8		

Turning to the classification of values of K proposed by Dickman, it must be pointed out that they were obtained under experimental conditions, in which distracting or mitigating factors are absent or negligible, and attention is focused wholly on the vibration. Such a dominant state

cannot fail to be reflected in subjective sensation as well as in the objective indices. Thus it seems to us that maximum permissible values of K near unity are extremely low, and it would seem to be without danger to health to admit higher values, such as K = 3 for a range of vibrational frequency from one to 30 c/s and K = 1-2.0 for a range from 30 to 100 c/s. The justification for this is the fact that, in many shops, the value of K reaches 1.5-3 without exerting any deleterious effects on the organism. This is especially the case with vibrations in textile mills.

If we calculate K for the amplitudes of vibration suggested by Geyger and Eason, we obtain values very close to our own:

For a range of frequencies up to	10 c/s	= 3.0
" "	20 c/s	= 2.4
" "	50 c/s	K = 1.3

Maximum permissible parameters of vibration have recently been proposed by Borshchevskiy and A. M. Volkov (1958). Borshchevskiy presents norms for vertical vibrations of brief duration; A. M. Volkov restricts neither the form of vibration nor the duration of its action. The data of the latter, with our own calculated values of K, are shown in Table 4, and those of the former in Table 5.

Table 4

Frequency, c/s	Amplitude, mm	K	Frequency, c/s	Amplitude, mm	K
Up to 2	4,0	16	10	0,050	2,5
3	1,5	13,5	20	0,012	1,2
4	0,8	12,8	30	0,009	1,3
5	0,4	10,0	40	0,008	1,6
6	0,15	4,5	50	0,007	1,4
7	0,10	3,5	75	0,003	0,6
8	0,075	3,0	100	0,0015	0,3
9	0,060	2,7			

Amplitudes of vibration up to seven c/s presented by A. M. Volkov are very large and perhaps dangerous. They are much in excess of the parameters of areas leading to injury. At high frequencies, of course, the amplitudes are less.

Table 5

Frequency in c/s	Am litude in mm	K
10-20	0,8	40-45
30	0,4	60
40-70	Less than 0,4	10-60

Only the area of frequencies from 8-10 to 30-50 c/s has acceptable values of amplitude for vertical vibrations sensible to a standing subject.

As concerns the maximum permissible amplitudes proposed by Borshchevskiy, we cannot accept them because the limiting amplitudes are extremely large and, obviously, may be admissible in the are of low frequencies (10-20 c/s) only for brief periods of time.

Reyer and Meyster made an attempt to evaluate by subjective sensation the effect of impulses of different frequency and degree of abruptness. An impulse lasting less than 0.031 seconds with an amplitude less than 0.01 cm may cause headache, pains in the small of the back, and epigastric discomfort. On heavy machines (scrapers, bulldozers, agricultural machines, and others), the number of impulses may be very great, reaching 30-80 per minute at an amplitude of two to 20 cm. Determination of maximum permissible amplitudes of impulses is an open question at the present time.

Returning to the question of assessing norms for mechanical vibrations of a periodic nature, we believe that separate norms should be set for vertical and horizontal vibrations. Normalization of complex vibrations should be carried out at the highest frequency in a given spectrum.

It is very expedient to use determinations of values of K for vertical vibrations, which makes it easy to compare

data of many studies, and comparison with physiological data would provide a basis for better-substantiated norms of values.

On Adaptation of the Organism to Prolonged Action of Radiant Energy

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The problem of the adaptation of the organism to the prolonged action of stimuli of the external environment, especially meteorologic conditions, is at the present time attracting the attention both of Soviet and of foreign authors (M. Ye. Marshak and N. K. Vereshagin, 1936; A. B. Lekakh, 1939; M. A. Abramovich, 1940; Taylor, Henschel, and others, 1943; Wyndham, Strydom, 1954; and others).

The authors in their studies characterize the final stage in adaptation of the organism, i.e., according to the conceptions of B. B. Koyranskiy (1957), the "period of relative adaptation." Such studies do not afford a complete idea of the dynamic of development of the process of adaptation, nor of the degree of adaptation of the organism to the action of the stimulus.

B. B. Koyranskiy, L. Ya. Ukvol'berg and T. V. Kuksinskaya (1956), studying the prolonged action of high environmental temperatures (40 degrees C) on the organism, established the phasic nature of the process of development of adaptation. The dynamic study of prolonged, repeated action of a meteorologic factor on the organism affords us the possibility of clarifying the physiologic changes which occur during the process of adaptation.

The purpose of our study was to investigate the effects of prolonged, repeated action of infrared rays of long wavelength λ_{max} = 2.2 microns and with an intensity of one cal$\cdot$cm^2/min. Studies were made of three subjects aged 21 to 23 years over a period of 70 days and, after an

interruption of three months, a second period of 40 days (average values shown are for ten-day periods). The order of observations was: from onset of the experiment, the subjects rested for 30-45 minutes, then were subjected to local irradiation (area of skin over the chest measuring 150 cm^2) for five minutes at a time six times at intervals of ten minutes. Physiologic changes were recorded at the end of each irradiation and during the recovery period.

For studying the physiologic changes arising in the process of adaptation of the organism, we used the following methods: determination of motor chronaxie with flexion of the fingers of the left hand (according to the topography of the basic motor points, after the method of D. A. Markov, "clinical Chronaximetry," 1935, appendix, table 16) of arterial pressure, of heart rate, of body temperature and skin temperature over the irradiated part, and of the extent of hyperemia of this area. Sweating reaction was studied by the electrometric method, based on the determination of the electrical resistance (by the method of Prof. N. N. Mishchuk). Heat sensitivity was determined by subjective reaction as "hot," "warm," or "Slightly warm."

In the process of adaptation of the organism to the prolonged, repeated action of this factor, there was a definite dependence on the response reaction of the organism. In the first period of action of infrared rays (I-II-III ten-day periods), there was a noticeable tendency to intensification of all physiologic functions (Fig. 1, 2). This, apparently, is explained by the fact that the action of this stimulus on the organism elicits a diffuse reaction on the part of the entire group of physiologic systems. In the following ten-day period of irradiation, there was a less pronounced shortening of chronaxie (see Fig.1) and in the VI-VII ten-day periods this shortening was at a minimum, which testifies to the onset of a relative equilibrium between the organism and the external environment.

Changes in chronaxie following irradiation in the direction of shortening were observed also by other authors. I. N. Nikitskiy notes that "upon intense irradiation (0.5-1 cal$\cdot cm^2$/min), reduction of chronaxie is more marked." M. Ye. Marshak, A. I. Levina, S. I. Lyakhovetskiy and others

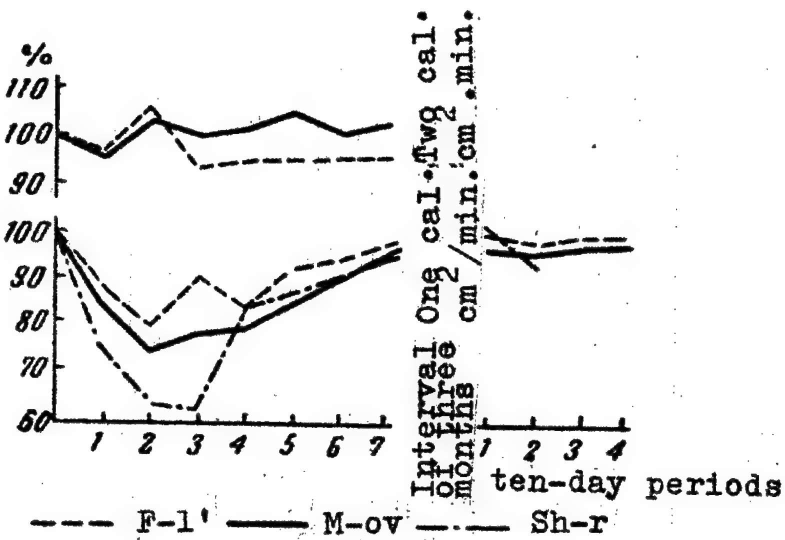

Fig. 1. Changes in magnitude of the motor chronaxie, expressed as percent of original values taken as 100.

observed, following prolonged irradiation (25-30 minutes), a biphasic change in chronaxie, in which during the first minutes of irradiation there was marked shortening of chronaxie, later superseded by a lengthening of it. A gradual weakening of the reaction to the effects of infrared rays is also seen on the part of the skin temperature of the irradiated area.

Table 1 shows average values of the curve of skin temperature during the process of adaptation of the organism to the action of infrared rays with an intensity of one cal·cm^2/min.

In the first ten-day periods of irradiation, the skin temperature increased abruptly from 38.5 to 39.5 degrees, whereas in later periods this increase attained only to 36.5-37.5 degrees. Apparently it is possible to speak of the fact that the original skin temperature is reduced (reorganization of the organism to a new level) along with a reduction in the sensitivity of receptors to the prolonged action of infrared radiation.

The time of restoration to normal of the skin temperatures also becomes shortened (Table 2).

Table 1

Changes in skin temperature of irradiated area (effect of one $cal \cdot cm^2/min$)

Observed ten-day period	M.		F.		Sh.	
	before irradiation	after irradiation	before irradiation	after irradiation	before irradiation	after irradiation
I	34,0	39,2	33,7	38,5	33,8	39,0
II	34,6	38,3	33,5	37,3	33,4	39,5
III	33,8	39,1	34,0	38,0	33,8	39,3
IV	33,7	38,7	33,6	37,8	34,0	38,4
V	33,7	39,2	33,7	38,0	—	—
VI	33,4	38,5	33,6	37,9	33,0	37,7
VII	33,1	37,5	33,0	36,6	33,3	37,9
After a three-month interval						
I	33,8	37,5	33,8	37,0	33,9	38,3
II	34,3	38,0	33,8	37,2	34,8	38,0
III	34,5	37,6	33,8	37,0	—	—
IV	34,4	38,0	34,0	37,1	—	—

Table 2

Time of restoration of skin temperature of the irradiated area in minutes

Subject	Intensity of irradiation	ten-day periods							After three-month interval	ten-day periods			
		I	II	III	IV	V	VI	VII		I	II	III	IV
F.	1 $cal.cm^2/min.$	40	30	30	15	15	18	15		20	18	17	15
	2 -id-	30	16	14	—	21	23	17					
M.	1 -id-	30	30	30	20	20	20	15		16	17	14	12
	2 -id-	24	14	12	10	10	16	18					
Sh.	1 -id-	30	20	20	17	—	15	17		17	15		

The data of Table 2 show that, in the first period of action of infrared irradiation, the "relative rate of reversion to the original condition" was 40-30 minutes, which testifies to the low lability of these tissues. In the process of "training," the lability of the tissues was much increased (rate of restoration increases almost three-fold), which ensures a higher work capacity of the tissues. According to A. A. Ukhtomskiy, "the more labile the tissue, the less it changes in its original function, i.e., it is functionally more stable and less exhaustible."

Prolonged action of infrared radiation was also reflected in the condition of the cardiovascular system (see Fig. 2). The first period was characterized by a certain increase in the systolic pressure, which depended on the state of stimulation of the vasomotor center and, as a result, of reflex constriction of the peripheral vessels. In the ensuing ten-day periods, this reflex subsided and became extinguished, as it were; the peripheral vessels, under the influence of the systematic action of infrared rays, dilate and the arterial pressure drops. During the VI-VII ten-day periods of irradiation, the arterial pressure becomes established at the level of the physiologic background. This testifies to the fact that the cardiovascular system becomes adapted to the systematic action of infrared rays which, evidently, is connected with a diminished flow of impulses from the receptor zones to the higher centers and to the medulla (Bainbridge).

Table 3 contains data on changes in the intensity of sweating reaction.

In the first ten-day periods of irradiation, the sweating reaction was weak. The activity of the sweat glands increased slightly by the III-IV ten-day periods, after which loss of heat by sweating decreased. In the final ten-day periods, the sweat reaction was more intense than in periods III and IV.

Increase in the secretory activity of the sweat glands is regarded by us as a defensive reaction of the organism against the action of infrared radiation. The reduction in the activity of the sweat glands is probably a result of over-stimulation of the secretory nerve fibers, and perhaps

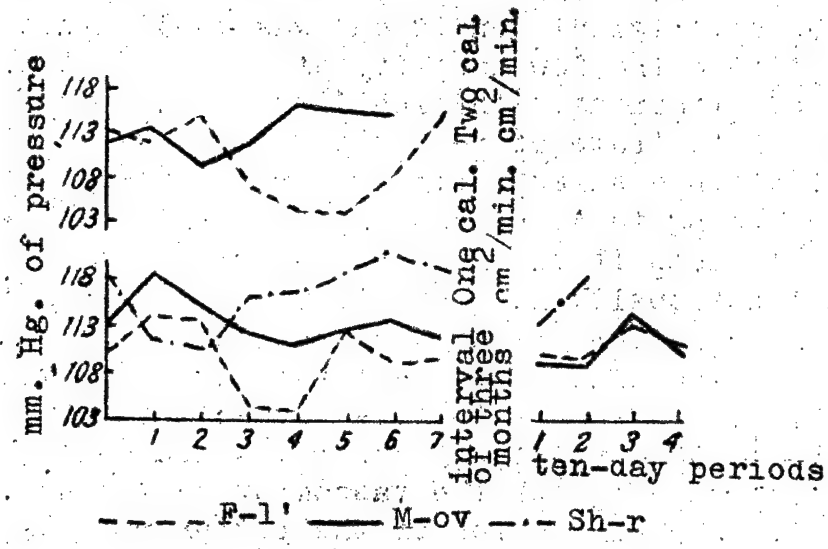

Fig. 2. Dynamic of maximum [systolic] arterial pressure

Table 3

Dynamic of intensity of sweating in relative units

Subject	Intensity of irradiation	ten-day periods							After three-month interval	ten-day periods			
		I	II	III	IV	V	VI	VII		I	II	III	IV
F.	1 cal·/cm²/min	2,6	1,6	3,0	1,8	1,6	0,6	2,8		–	–	–	–
	2 cal·/cm²/min	–	0,8	0,4	1,6	–	–	–		–	–	–	–
M.	1 cal·/cm²/min	–	0,5	2,4	0,2	0,3	1,6	4,8		2,0	7,2	1,9	2,1
	2 cal·/cm²/min	11,1	16,0	11,9	16,5	17,3	15,6	18,8					
Sh.	1 cal·/cm²/min	0,4	–	1,2	0,5	–	1,7	2,7		1,0	1,8	–	–

of the centers as well (B. B. Koyranskiy). A sense of heat in the first five to seven days was defined by the subjects as "warm," but only as "slightly warm" on the following days. On the first days there was a mild hyperemia of the irradiated area, whereas later no hyperemia was seen. On days of irradiation, the body temperature varied from 0.2 to 0.3 degrees. Observations conducted after a prolonged interruption (three months)(see Figs. 1, 2, Tables 1 - 2), showed that the effect of infrared radiation did not cause in these cases the same changes in the organism as were manifested in the first ten-day periods of irradiation.

Apparently, this stimulus (intensity of infrared radiation of 1 cal·cm^2/min) leaves a "trace" reaction for a long time after termination of the stimulus. There is evidence that the process of adaptation to various influences occurs without particular stress on defensive adaptations if the initial stimulus on the organism is weak (A. B. Lekakh, Stridom, Wyndham et al., M. Ye. Marshak et al.). For elucidation of this matter, we continued their observations with a stronger stimulus, subjecting the subjects to infrared irradiation with an intensity of two cal·cm^2/min. Studies were continued with two subjects for a period of 70 days.

As can be seen from Fig. 1, the action of infrared radiation with an intensity of two cal·cm^2/min does not cause a marked shortening of the chronaxie, as was the case with the action of one cal·cm^2/min. This testifies to the fact that preliminary "training" of the organism to weaker stimuli increases its resistance to the effects of the same factor but with greater intensity.

In comparing the changes in systolic arterial pressure in two series of observations (see Fig. 2), it should be noted that the reaction of the cardio-vascular system following irradiation with an intensity of two cal·cm^2/min is similar to the reaction see in the first series, i.e., there is the same phasic character in the process of adaptation but it is less apparent. The heart rate during the entire period of irradiation varied within the limits of two to five beats per minute [presumably the range of variation rather than the mean heart rate].

In the first ten-day periods of irradiation (Table 4),

the temperature reaction of the skin to irradiation with an intensity of two $cal \cdot cm^2/min$ was only slightly more marked than following irradiation with one $cal \cdot cm^2/min$, despite the fact that the strength of the stimulus was doubled.

Table 4

Changes in the skin temperature of the irradiated area (effects of irradiation with two $cal \cdot cm^2/min$)

ten-day periods	M.		F.	
	before irradiation	after irradiation	before irradiation	after irradiation
I	33,4	39,5	33,5	38,3
II	33,4	39,0	33,8	38,1
III	33,4	38,9	33,6	37,9
IV	32,9	37,5	—	—
V	32,5	37,2	32,2	36,6
VI	32,7	37,8	32,4	36,9
VII	32,6	37,6	32,4	36,9

The reduction of the skin temperature of the irradiated area began during the III ten-day period, i.e., on the 20th to 30th day, or 20 to 30 days earlier than in the first series of observations, which confirms the opinion that preliminary training of the organism to a weak stimulus considerably accelerates the onset of reduction of sensitivity of the thermoreceptors to heat. Reduction in the original temperature of the skin of the irradiated area occurs much earlier, ie.e, during the IV and V ten-day periods. The time of restoration of the skin temperature is shortened as of the II ten-day period (see Table 2). Following the action of one $cal \cdot cm^2/min$, shortening of the time of restoration of skin temperature was noticed during the IV ten-day period.

The sweat reaction in subject M. (see Table 3) was more intense in all ten-day periods of irradiation. In subject F., this reaction was less pronounced than in the first series of observations, and in the later ten-day

periods, no sweating was seen at all. Despite this fact, the skin temperature in subject F. was slightly lower than in M. Such a reaction on the part of the secretory activity of sweat glands in subject F. is apparently explained by the fact that F. was exposed during this period simultaneously to the action of two stimuli: infrared radiation with an intensity of two cal·cm^2/min and to a cold factor (winter bathing) (subject F. began winter bathing during the final two ten-day periods of the second series of observations). It would seem that the latter stimulus was the stronger, as seen in the reversal of the sweat reaction.

On the basis of our findings, it is possible to draw the following conclusions:

(1) The process of development of adaptation (in the course of 70 days) to the effects of infrared radiation with an intensity of one cal·cm^2/min follows a triphasic course: the first phase is a period of initial adaptation, for which it is characteristic to observe a marked increase in the skin temperature and the time of its restoration, an increase in arterial pressure and a shortening of chronaxie; the second phase is characterized by stress of the thermoregulatory reactions, which is reflected in a marked suppression of the activity of the sweat glands and a reduction in arterial pressure; the third phase is the establishment of relative adaptation; during this period the reactions of the organism become less pronounced.

(2) After an interval (three months), changes in the physiologic reactions to the action of the stimulus retained their initial direction, which indicates the relative stability of the process of adaptation.

(3) Preliminary training of the organism to the prolonged action of a weak stimulus (with an intensity of infrared radiation of one cal·cm^2/min).

Bibliography

Abramovich, M. A., in the book "Changes in the organism upon the action of radiant energy and upon cooling," Khar'kov, 1940, 78.

Bainbridge, F. A., "The physiology of muscular activity," Moscow-Leningrad, 1927, 152.
Bykov, K. M., "Selected writings," Moscow, 1954, Vol. 2.
Koyranskiy, B. B., Gig. Truda i Prof. Zabolevaniya [Work Hygiene and Occupational Diseases], 1957, No. 2, 6.
Koyranskiy, B. B., Ukvol'berg, L. Ya., Kuksinskaya, T. V., "Theses of reports at the scientific session in celebration of the 30-year activity of the Institute of Work Hygiene and Occupational Diseases," Leningrad, 1954, 17.
Levina, A. I., Gig. Truda i Tekh. Bezopasnosti [Work Hygiene and Techniques of Safety], 1937, No. 6, 29.
Lekakh, F. A., "Works and materials of the Dnepropetrovsk Institute of Work Hygiene and Occupational Diseases," Dnepropetrovsk, 1939, Vol. 9, 65.
Likhovetskiy, S. I., ibid, 98.
Marshak, M. Ye., Arkh. Biol. Nauk [Archives of the Biological Sciences], 1935, Vol. 38, No. 1, 121.
Marshak, M. Ye., Vereshagin, N. K., Byull. Eksper. Biol. i Med. [Bulletin of Experimental Biology and Medicine], 1936, Vol. 1, No. 1, 55.
Nikitskiy, I. N., ibid. 1937, Vol. 3, 517.
Taylor, H. L., Henschel, A. F., Keys, A., Am. J. Physiol., 1943, Vol. 139, 583.
Wyndham, C. H. et al., Arbeitphysiologie, 1954, Vol. 15, 373.

Materials on the Toxicology of Radioactive Iron

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The radioactive isotope of iron, Fe^{59}, has found extensive use in different branches of the national economy. Work is carried on with open isotopes, for the most part in the powdered state. The use of isotopes under industrial conditions creates the possibility of active aerosols. Fe^{59} is used in biology, medicine, and agriculture, usually in the form of solutions of salts of radioactive iron, for the study of metabolic processes, plant nutrition, hematopoietic processes, and so forth.

We studied the air in a metallurgy plant, in a cement plant, and in a scientific research institute of the autotractor industry. In the first, Fe^{59} was being used in the form of a powder of the iron oxide for control of the movements of charging materials in open-hearth furnaces. In the cement plant, Fe^{59} was also being used in the form of the oxide for studying the process of mixing of the clinker in revolving furnaces, and finally, in the scientific research institute of the autotractor industry, Fe^{59} was being used in the form of inserts of metallic iron for the control of the deterioration of units. In all cases the activity of the samples was comparatively low and did not exceed 50 microcuries.

We did not manage to discover radioactive dust in the air of the production sites, which may to a certain degree be attributed to the imperfections of the method of sampling which we used (filter material was ordinary filter paper). However, tests of working surfaces and equipment at the sites of production involving the use of Fe^{59} (unpacking, storage, handling of samples) demonstrated a considerable contamination with radioactive substances. In a number of cases, the number of beta-particles per minute over an area of 150 cm^2

reached 30,000. The latter, in the event of more extensive use of Fe^{59}, creates the threat of accumulation of radioactive contamination and the formation of radioactive aerosols.

In connection with the possibility of entry into the organism of small amounts of Fe^{59}, particular importance attaches to a study of the chronic effects of radioiron on the organism.

Findings on the chronic effects of radioactive iron and on its behavior upon entry via the respiratory passages do not exist in the literature available to us. However, it is precisely this route which is the most probable under industrial conditions and which represents the greatest danger.

In the works of E. B. Kurlyandskaya and D. I. Zakutinskiy and associates, it has been shown that the biologic effects of small amounts of incorporated radioactive substances depend on the physico-chemical properties of these substances, the routes of entry, and the character of their behavior in the organism. In order to determine, on biologically-sound bases, the maximum permissible limits of concentration of aerosols of Fe^{59} in the air, we studied the toxic effects of small doses of different compounds of radioactive iron (the soluble citrate and the insoluble iron oxide) following entry into the organism through the respiratory passages.

In the process, we used the preparations most frequently encountered in industrial and scientific research work. The preparations contained admixtures of Co^{60}, to the extent of 12 percent of the total activity. The amounts by weight were vanishingly small.

In a preliminary experiment we studied the distribution and excretion of different compounds of Fe^{59} following intratracheal administration of them. The experiments were run on adult white rats. The preparations were given according to the method of G. N. Gorodenskaya. One group of rats (20 animals) was given a neutral solution of Fe^{59} citrate, with an activity of 20 microcuries, in amounts of one ml per rat. A second group of rats (18 animals) was given Fe^{59} oxide with the same activity in the form of a mixture of a

finely-dispersed powder in physiologic saline, ten mg of the dry powder being given in one ml of physiologic saline to each rat.

The animals were placed in metabolism cages for separate collection of urine and feces and were sacrificed at different times from the amount of administration. The radioactivity of the tissues was measured in a "B" apparatus with the use of a cylindrical counter.

The distribution of Fe^{59} according to organs upon administration of the soluble compound is shown in Fi. 1.

As can be seen from the data presented, 24 hours after administration of Fe^{59} citrate, 22.2 percent of the original amount could still be found at the site of introduction. During the subsequent day, the amount of iron continued to diminish, but much more slowly, and by the 30th day only 9.2 percent of the administered activity could be found in the lungs.

The cause of the long retention of a part of the administered compound in the lungs is apparently to be sought in the formation of coilloidal compounds of iron, which are only very slowly absorbed.

The basic amount of Fe^{59} absorbed from the lungs is distributed throughout all the organs and tissues of the organism, with predominant accumulation in the liver, bone marrow, and blood. The highest specific content of Fe^{59} is found in the bone marrow (2.8 percent per gm of tissue). In the blood, Fe^{59} appears within several hours, but the highest levels are reached in seven to ten days, at which time about 11 percent of the administered iron is contained in the blood (0.5 percent per ml of blood).

Consequently, iron given into the lungs later gains access to the general iron pool in the organism and enters the bone marrow, where it is used in the synthesis of hemoglobin. In the spleen, kidnes, muscles, and other organs, considerable amounts of Fe^{59} are found up to the 30th day after administration.

The excretion of Fe^{59} following this mode of administration is accomplished both by the kidneys and by the gastrointestinal tract. All told, after 16 days, 31.7 percent had been eliminated in the feces and 23.1 percent in the

urine (percentages of original dose). The half-life (biological) was ten days.

A totally different picture of the distribution of Fe^{59} is seen when it is given into the lungs as a mixture of the insoluble iron oxide.

Upon administration of Fe^{59} oxide, 61 percent of the original dose is still in the lungs on the 30th day after administration (76 percent is found in the lungs the first hour after administration). Consequently, 30 days suffices only to reduce the quantity of iron by 15 percent in the lungs. On the first day, a considerable concentration of Fe^{59} is found in the gastrointestinal tract, which is explained by the swallowing of a certain amount of the preparation following the intratracheal administration. In the liver, bone marrow, spleen and blood, only traces of the radioactive iron were found.

Hence, in comparing the distribution of soluble iron citrate and insoluble iron oxide administered into the lungs, it is possible to note that Fe^{59} citrate, although some of it remains in the lungs (9.2 percent), is mostly absorbed from the lungs and distributed throughout the organs, with preferential accumulation in the liver and blood, whereas Fe^{59} oxide is almost completely retained in the lungs, and remains there for long periods, being excreted only slowly, primarily in small amounts along with the sputum.

For a characterization of the radiotoxic effects of Fe^{59}, we investigated hematologic, certain physiologic, and pathologic changes occuring in the organism of animals under the influence of different compounds of Fe^{59} introduced into the lungs. The long retention of the iron compounds in the lungs permitted us to follow these changes for a period of 15 months after single or triple administration of the preparation.

We made studies of 80 white rats. The preparation was administered to the animals intratracheally. Fe^{59} citrate was given in the form of a neutral isotonic solution in amounts of one ml per rat. Iron oxide was given in the form of a mixture of finely-dispersed powder in physiologic saline. Each rat was given one ml of the mixture containing 12 to 15 mg of the powder. In animals dying in the process

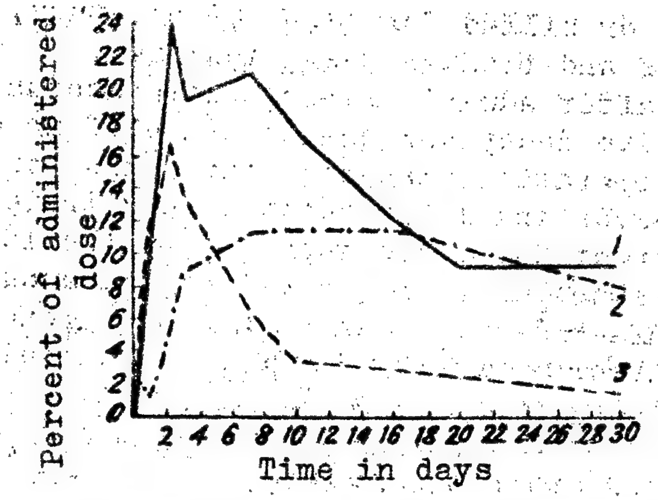

Fig. 1. Contents of Fe^{59} in organs and tissues following administration of iron citrate.
1 - liver; 2 - blood; 3 - bone marrow

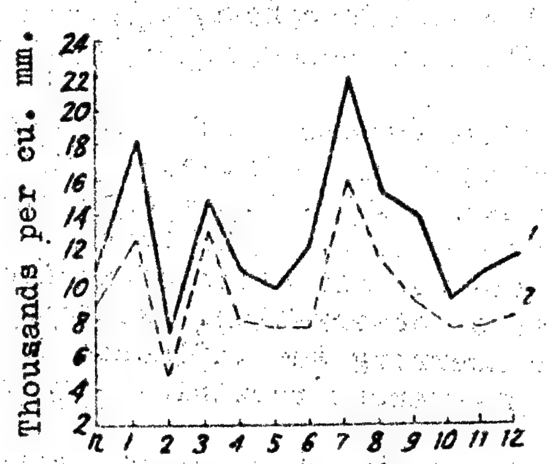

Fig. 2. Variations in the leykocyte and lymphocyte counts in rats receiving the oxide of radioactive iron in amounts of 3.36 microcuries.
1 - leukocytes; 2 - lymphocytes

of the experiment or killed for purposes of study, the activity of the organs and tissues was determined.

15 months after administration, with account being taken of radioactive decay and the presence of an admixture of Co^{60} in the preparation employed, the lungs contained 28 percent iron oxide and 2.2 percent iron citrate.

Calculation of the doses received by the lungs could not be computed, since only an inconsiderable amount of the energy of the gamma-radiation, which has high penetrating capacities, was absorbed by the lungs. The animals were sacrificed in seven groups. The characteristics of the separate groups and the tissue doses of beta-radiation received by the lungs are shown in the table.

Upon systematic o observation of animals, no cases of acute radiation sickness were seen. However, as is apparent from the tabular data, among animals receiving Fe^{59} oxide in amounts of 27.5 - 3.36 and 1.06 microcuries there was a higher mortality, caused by inflammatory injury to the lungs and the development of bronchogenic tumors, with total doses of radiation to lungs nonetheless being comparatively low.

The quantitative changes in the indices of the peripheral blood following single intravenous injection of Fe^{59} to rabbits in amounts of 3.75 - 7.5 microcuries are pointed out by L. B. Stolyarova and R. D. Nikitenko. In this, the authors comment on the normalization of indices of blood by the 10th to 12th day of observation. No data could be found in the literature concerning the influence on the blood system of radioactive substances remaining for long periods in the lungs.

In our experiments, with dynamic observations of the state of the peripheral blood, not a single instance of damage to the blood could be detected which corresponded to the pronounced form of radiation sickness. Changes in the peripheral blood were reflected chiefly in instability of the indices of the white blood cells, with marked variations in the leukocyte and lymphocyte counts in the direction of increase, and in quantitative changes in the white blood cells.

The above-noted changes were, to some extent, seen in

Table

No. of group	No. of animals	Administered preparation and activity in microcuries	Ratio to maximum permissible dose upon single inhalation according to Morgan	Dose of radiation received by lungs on first day in rads	Dose of radiation received by lungs during 15 months in rads	No. of animals dying in 15 months	Cases of lung cancer
1	9	Fe^{59} citrate - 20	More than 100 times	70	587	1	-
2	12	Fe^{59} oxide - 27.5	More than 250 times	206	9,790	4	2
3	15	Fe^{59} oxide - 3.36	More than 30 times	26	1,296	3	3
4	10	Fe^{59} oxide - 1.06	More than 10 times	8.5	484	3	3
5	15	Fe^{59} oxide - 0.03[1].	Max. permissible dose	0.21	138	2	-
6	8	Oxide of stable iron	-	-	-	-	-
7	11	Physiological control	-	-	-	-	-
Total	80					13	8

1. Animals of the fifth group were given Fe^{59} oxide in amounts of 0.03 microcurie three times at intervals of 1½ months.

animals of all groups; however, the frequency and expression of the separate phenomena were not identical.

Variations in the indices of the red blood - hemoglobin, erythrocytes, and reticulocytes - both in rats subjected to the action of Fe^{59} and in control groups, did not exceed the limits of physiologic norms. The erythrocyte counts varied within limits of 5800 thousand to 9600 thousand, and the hemoglobin from 77 to 105 percent.

In groups of animals receiving Fe^{59} oxide in amounts of 27.5-3.36 and 1.06 microcuries (Fig. 2), there was leukocytosis (up to 29,000), caused by an increase in the number of neutrophils to 11,000 and of lymphocytes to 19,000; however, in these groups, individual animals showed variations in leukocyte counts which did not exceed physiologic limits (6,700-18,200), which testifies to the dissimilar sensitivity of animals to ionizing radiation.

In animals receiving citrate of radioactive iron, leukocytosis was primarily associated with an increase in the number of neutrophils. Whereas in the control group the number of neutrophils varied within limits of 1,100 to 4,500, in animals receiving citrate of Fe^{59} the variations were within limits of 1,700 to 11,800, there being a shift to the right in the neutrophilic differential count in a number of cases.

The quantitative changes in the elements of the white blood were the most constant feature observed (fragmentation and hypersegmentation of the nuclei of neutrophils, cytolysis of lymphocytes), which were noted by the third to fifth month after administration of the preparation.

At later dates, there was a certain normalization of the indices of the peripheral blood, which might be explained by the effects of the compensatory forces of the organism and the gradual reduction in the activity of the preparation administered.

The above-enumerated changes in the composition of the peripheral blood are similar to those described earlier by N. L. Beloborodova and Ye. F. Baranova during the chronic administration of strontium, ruthenium, and cesium, and may be characterized as the initial phases in disruption of hematopoiesis.

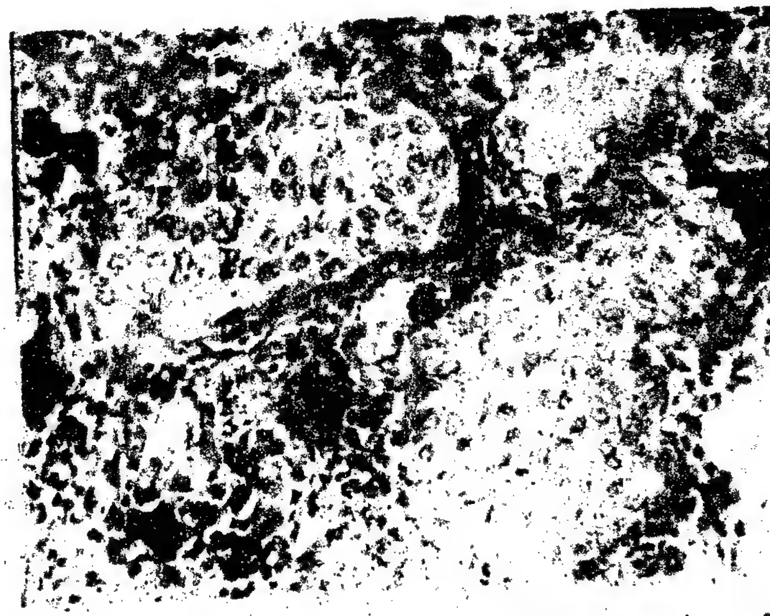

Fig. 3. Microphotograph. Lungs. Metaplasia of the epithelium of the bronchial mucosa, converting it from cylindrical into compound squamous with manifestations of anaplasia characteristic of a precancerous condition (Magnification 10 x 40)

In animals receiving Fe^{59} oxide in amounts of 0.03 microcuries three times, the changes in the indices of peripheral blood were not pronounced and not so regularly observed as in animals receiving preparations of Fe^{59} with greater activity. Of 15 animals of this group, neutrophilic leukocytosis (more than 6,000) was seen only in four.

In the works of M. I. Nemenov, Ye. I. Bakin, A. V. Lebedinskiy, Yu. K. Kuritskiy and other authors, concerning principally the effects of external irradiation, it was shown that the nervous system possesses a very high sensitivity as well as a great anatomical resistance to the effects of penetrating radiation. This circumstance compelled us along with our observations of the state of the peripheral blood to do studies of certain functional changes in the central nervous activity of animals subjected to the action of Fe^{59} oxide in amounts of 0.03 microcurie.

For characterization of the functional state of the

central nervous system, we performed studies of the capacity of the central nervous system for summation of subliminal stimuli. These studies involved the use of a device permitting regulation of the strength and frequency of electrical stimulation of the animals. The impulses of stimulation were administered with a constant frequency of 120 impulses per minute.

These studies showed that in animals repeatedly receiving Fe^{59} oxide in amounts of 0.03 microcurie, there is a reduction in the capacity of the central nervous system for summation of subliminal stimuli. The average number of impulses causing a reaction of the animal was 37 at the beginning of the experiment, whereas after six months, it was 59.

These data indicate that, upon the action of Fe^{59} oxide in minimal doses, there are functional disruptions in the central nervous system expressed as a lowering of the capacity of the central nervous system for summation of subliminal impulses.

Fig. 4. Microphotograph. Lungs. Foci of squamous, keratinizing carcinoma. (Magnification 10 x 40).

Pathologic studies of organs of animals both dying and killed at various dates after the moment of administration of the preparations of radioactive iron, the most pronounced changes were seen in the lungs. (The work was carried out under the direction of Prof. P. P. Dvizhkov, with the consultation of T. A. Kochetkova.) The nature of the histologic changes was uniform in all groups, but the extent varied depending on the type of compound administered and its activity.

The earliest changes, which appeared within three to four months, were inflammatory changes in the bronchi and sclerotic changes in the pulmonary tissue in the form of focal thickening of the interalveolar septa, alternating with areas of emphysema. After the sixth to ninth month of action, the overwhelming majority of animals exhibited chronic suppurative processes in the bronchi, leading to the development of bronchiectasis and abscesses, with marked sclerotic changes in the peribronchial tissues and, in a number of cases, metaplasia of the connective tissues into osseous tissues and formation of groups of epithelial cells characterizing a precancerous condition (Fig. 3).

These changes were noted in animals of all groups, but whereas in eight of 37 animals receiving Fe^{59} oxide in amounts of 27.5-3.36 and 1.06 microcurie, there was development of bronchogenic squamous cell carcinoma of the lungs (Fig. 4) against a background of severe inflammatory changes, in the animals receiving Fe^{59} oxide three times in amounts of 0.03 microcurie and Fe^{59} citrate in amounts of 20 microcuries, the degree of development of inflammatory phenomena was much less pronounced, and there was no evidence of a tumor process.

In the works of Cember, T. A. Kochetkova and G. A. Avrunina, there is evidence of development of lung cancer under the influence of the action of radioactive substances administered by the respiratory route. The total dose of radiation of the lungs under these conditions was of the order of 1,500 to 30,000 rads, which in a number of cases led to the development of acute radiation sickness in the experimental animals. In our experiments, development of neoplasms in the lungs was seen with smaller tissue doses

against a background of minimal manifestations of radiation sickness.

Our data testify to the fact that different compounds of Fe^{59} have high radiotoxicity when they gain access to the body by way of the respiratory tree, which may serve as a biological basis for determination of the maximum permissible concentrations of Fe^{59} in the air.

Considering that the development of lung cancer is seen in animals receiving $Fe^{59}{}_2O_3$ in amounts exceeding the maximum permissible limit for single inhalation (according to Morgan) by ten times, and that, upon the action of the maximum permissible dose, there are disturbances both of a functional and of a morphological nature, a reduction by two orders of magnitude in the maximum permissible concentration is recommended for insoluble compounds.

Conclusions

(1) There are essential differences in the distribution and elimination of soluble and insoluble compounds of Fe^{59} when given intratracheally.

(2) In animals receiving Fe^{59} citrate in amounts of 20 microcuries, there were marked variations in the quantitative indices of the white blood, primarily in the direction of increase and the development of suppurative inflammatory processes in the bronchi with marked sclerotic changes in the peribronchial tissues.

(3) In animals receiving Fe^{59} oxide in amounts of 27.5-3.36 and 1.06 microcuries, the changes discovered were uniform and were expressed as a marked instability of the indices of the white blood and the development of bronchogenic carcinoma of the lungs against the background of a chronic inflammatory process.

(4) In animals receiving FE^{59} in amounts of 0.03 microcurie three times, which is at the level of the maximum permissible concentration of Fe^{59} in the lungs (according to Morgan), there were distrubances in the functional condition of the nervous system and morphologic changes in the lungs of an inflammatory and sclerotic nature.

(5) The data obtained may serve as a biological basis for the reduction of the maximum permissible concentration by two orders of magnitude for insoluble compounds of Fe^{59} in air.

Bibliography

Bakin, Ye. I., Vestn. Rentgenol. i Radiol. [Herald of Roentgenology and Radiology], 1951, No. 3, 3.

Beloborodova, N. L., Baranova, Ye. F., in the book, "Materials on the toxicology of radioactive substances," Moscow, 1957, Vol. 1, 151.

Kudritskiy, Yu. K., Vestn. Rentgen. i Radiol., 1955, No. 6, 15.

Lebedinskiy, A. V., "The influence of ionizing radiation on the animal organism," Moscow, 1955.

Nemenov, M. I., "X-ray therapy by way of its effect on the nervous system," Leningrad, 1950, 28.

Stolyarova, L. B., Nikitenko, R. D., in the book, "Experience in the use of radioactive isotopes in medicine," Kiev, 1955, 200.

Marinelli, L. D. et al., Am. J. Roentgenol., 1948, Vol. 59, 260.

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